

LCA for Food Products (Subject Editor: Niels Jungbluth)

Case Study

Shift in the Marginal Supply of Vegetable Oil*

Jannick H. Schmidt^{1**} and Bo P. Weidema^{1,2}¹ Department of Development and Planning, Aalborg University, Fibigerstraede 13, 9220 Aalborg East, Denmark² 2.-0 LCA Consultants, Dr. Neergaards Vej 5A, 2970 Hoersholm, Denmark

** Corresponding author (jannick@plan.aau.dk)

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Abstract

Background, Aims and Scope. The consequential approach to system delimitation in LCA requires that consideration of the technologies and suppliers included are 'marginal', i.e. that they are actually affected by a change in demand. Furthermore, co-product allocation must be avoided by system expansion. Vegetable oils constitute a significant product group included in many LCAs that are intended for use in decision support. This article argues that the vegetable oil market has faced major changes around the turn of the century. The aim of this study is to study the marginal supply of vegetable oil as it has shifted to palm oil and describe the product system of the new supply.

Methods. The methods for identification of marginal technologies and suppliers and for avoiding co-product allocation are based on the work of Weidema (2003). The marginal vegetable oil is identified on the basis of agricultural statistics on production volumes and prices. A co-product from palm oil production is palm kernel meal, which is used for fodder purposes where it has two main properties: protein and energy. When carrying out system expansion, these properties are taken into account.

Results. The major vegetable oils are soy oil, palm oil, rapeseed oil and sun oil. These oils are substitutable within the most common applications. Based on market trends, a shift from rapeseed oil to palm oil as the marginal vegetable oil is identified around the year 2000, when palm oil turns out to be the most competitive oil. It is recommended to regard palm oil and its dependent co-product palm kernel oil as the marginal vegetable oil. The analysis of the product system shows that the demand for 1 kg palm oil requires 4.49 kg FFB (oil palm fruit) and the displacement of 0.035 kg soybeans (marginal source of fodder protein) and 0.066 kg barley (marginal source of fodder energy).

Discussion. The identification of the marginal vegetable oil and the avoidance of co-product allocation by system expansion showed that several commodities may be affected when using the consequential approach. Hence, the product system for vegetable oils is relatively complex compared to traditional LCAs in which average technologies and suppliers are applied and in which co-product allocation is carried out by applying an allocation factor.

Conclusions. This article presents how the marginal vegetable oil can be identified and that co-product allocation between oils and meal can be avoided by system expansion, by considering the energy and protein content in the meal, which displaces a mix of the marginal sources of energy and protein for animal fodder (barley and soy meal, respectively).

Recommendations and Perspectives. The implication of a shift in the marginal vegetable oil is significant. Many LCAs on rapeseed oil have been conducted and are being used as decision support in the bio energy field. Thus, based on consequential LCA methodology, it is argued that these LCAs need to be revised, since they no longer focus on the oil actually affected.

Keywords: Consequential LCA; co-product allocation; marginal data; methodology; palm oil; rapeseed oil; system expansion; vegetable oils

Introduction

The consequential approach to system delimitation in LCA (Weidema 1993, Weidema 2003, Ekvall & Weidema 2004, Hansen 2004) requires that the technologies and suppliers included in the analysed systems are those that change in response to a change in demand. In a somewhat sloppy shorthand, these are often termed the 'marginal technologies' or the 'marginal suppliers', as opposed to the average technologies or suppliers applied in traditional attributional LCA modelling. With a worldwide annual production of around 110 million tons, vegetable oils constitute a significant product group with vast applications for different food purposes as well as oleo-chemical and energy purposes. Currently, the vegetable oil market has been subjected to major changes that apparently involve a shift from rapeseed oil to palm oil as the marginal vegetable oil. We identify the causes for this shift and its implications for LCAs of products using vegetable oils.

Previously, rapeseed oil was identified as the marginal oil in Weidema (1999) and Weidema (2003), based on EU forecasts and information from Unilever, a major oil consumer and, at that time, also a major producer. Several studies have been conducted using rapeseed oil as the affected oil, e.g.

* **ESS-Submission Editor:** Prof. Walter Klöpffer, PhD
(walter.kloepffer@t-online.de)

Nielsen et al. (2005), Weidema et al. (2005) and Senter-Novem (2005). In addition, the entry of vegetable oils in LCA is not limited to LCAs where oil is used. When applying system expansion in order to avoid co-product allocation, vegetable oils also enter into LCAs of products where vegetable oil is co-product of the product of interest, typically protein feeds, e.g. fish and soy meal (Thrane 2004, Weidema 1999). Thus, a shift in the marginal oil from rapeseed to palm oil also affects LCAs where protein is a raw material or a co-product.

1 Purpose of the Study

The purpose of this study is to document that the marginal supply of vegetable oil has shifted from rapeseed oil to palm oil and to describe the product system of the new marginal vegetable oil supply.

2 Methods

Consequential system delimitation, which is comprehensively described by Weidema (2003), is different from traditional/attributional system delimitation in two ways; i) the included processes are those which are expected to be affected by a change in demand, i.e. the processes supplying the marginal product instead of processes supplying the average products used in attributional LCA modelling; and ii) co-product allocation is avoided by system expansion instead of applying allocation factors. A marginal technology is defined as the technology actually affected by a change in demand, and is identified as the one most sensitive to changes in demand. The marginal technology must be identified within the relevant market segment and among those which are flexible, i.e. not constrained by legal, physical or market conditions. Only substitutable technologies should be considered. In situations with an increasing or constant market trend, the marginal technology is identified as the most competitive technology. Reversely, in situations with a decreasing market trend, the marginal technology is identified as the least competitive technology. The most or least competitive technology can be determined primarily on the basis of the price relations between the technologies.

The study presented in this article includes two components; 1) the identification of the marginal supply of vegetable oils and 2) determination of the product system, i.e. avoiding co-product allocation by system expansion and the identification of the marginal supply of the substitute for co-products. The first component includes identification of the relevant market segment, flexible vegetable oils and substitutable vegetable oils. The identification of the marginal vegetable oil is then identified as the most competitive oil. The oils competitiveness is determined from price relations. The second component includes the identification of the co-products. For each co-product, the marginal supplier of the substitute is identified. The co-products of these substitutes are also identified. The resulting affected system is determined using linear algebra.

As it appears from the results of this article, the marginal supply is not necessary constant over time. Changes in the market situation, in the regulation or in constraints on

the production may cause changes in the marginal supply. This is valid for the identification of the marginal supply of the commodity of interest as well as for the possibly displaced system.

3 Results

3.1 Identification of marginal vegetable oil

According to Oil World (2005), the market trend for vegetable oils is increasing, and palm, soy and rapeseed oils are expected to remain growth leaders. Fig. 1 shows the market trend for the four most important oils. Fig. 2 shows prices and price forecasts for soy oil, sun oil and palm oil, relative to rapeseed oil, and Table 1 shows food applications and substitutions of different vegetable oils.

When identifying the marginal vegetable oil, this oil must belong to the relevant market segment. Different vegetable oils have different fatty acid compositions. Therefore, veg-

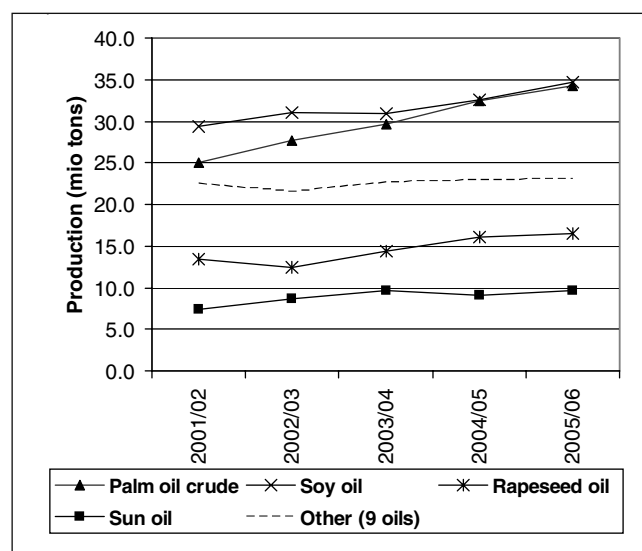


Fig. 1: Production of vegetable oils. Figures for 05 and 06 are estimates. Source: Oil World (2005)

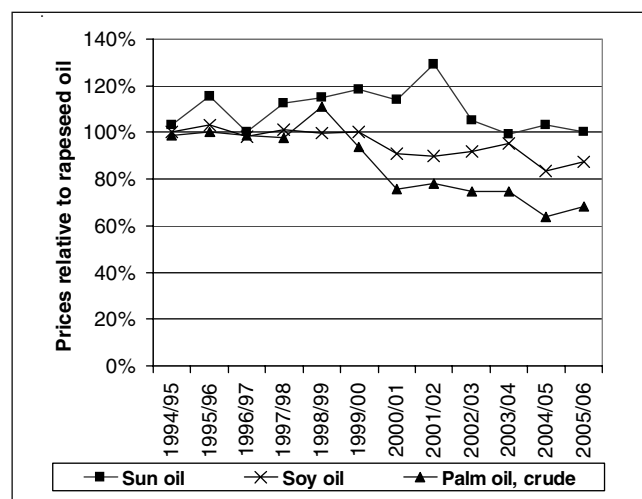


Fig. 2: Prices and price forecasts for sun oil, soy oil and palm oil relative to rapeseed oil. Figures for 05 and 06 are estimates. Source: Oil World (2005)

Table 1: Applications and substitutions of different vegetable oils and fats. (ph) is an abbreviation of 'partially hydrogenated'. Based on (Clay 2004, p. 183)

| Application | Seed oils (soy, rape, sun) | Palm oil | Lauric oils (Palm kernel and coconut) |
|-------------------------------|-------------------------------|----------|--|
| Solid fats | | | |
| Spreads, margarine, vanaspati | ×(ph) | × | × |
| Shortenings | ×(ph) | × | |
| Confectionary fats | ×(ph) | × | |
| Frying fats | | × | |
| Ice cream fats | ×(ph) | × | × |
| Liquid fats | | | |
| Frying oils | × | × | |
| Salad oils | × | × | |

etable oils are in general not completely substitutable. The demands of some applications can only be met by a few oils, while the demands of the major applications of vegetable oils can be met by several oils (see Table 1). This article deals with the bulk of oils that covers the major applications. The major food applications of vegetable oils are frying oil/fat, margarine, shortening and salad oils (Bockisch 1998). Other important applications are energy production and, to a lesser extent, industrial oils (soaps, detergents etc.). All major oils can be used for energy production.

It appears from Table 1 that the major seed oils (soy, rape and sun) and palm oil are generally substitutable, while lauric oils (palm kernel and coconut) have a lower substitutability. Thus, for the general vegetable oil market, the marginal oil has to be found among soy, rape, sun or palm oil.

It appears from Fig. 2 that since 1999/00, the most competitive oil has been palm oil followed by soy oil. Before 1999/00, only little difference between rapeseed oil, soy oil and palm oil can be seen. From 1994 to 2000, rapeseed oil was among the most competitive oils, but after that, the price has increased due to increased demand for bio diesel in the EU (Dahl 2005). The demand for bio diesel is responsible for most of the increase in the EU disappearance of rape, since rapeseed is still the key material for bio diesel (Oil World, 2005, p. 19–20). However, other oils also face an increasing demand for use in bio diesel, so increase in prices may also be expected here. During the period from 1994 to 2005, sun oil has in general been the least competitive of the four oils. According to Fig. 1, palm oil has been the fastest growing oil from 2001 to 2005, and according to Oil World (2005), palm oil is forecasted to remain the biggest growth market and to expand its market shares at the expense of other oils, although the growth rate to some extent is estimated to slow down. In FAPRI (2006), palm oil is forecasted to remain the cheapest vegetable oil during 2005/06 to 2015/16 while rapeseed oil prices are predicted to exceed the price of sun oil. Also in FAPRI (2006), the difference between soy oil and palm oil is predicted to increase. Thus, it seems that palm oil will continue to be the most competitive oil in the years to come. In addition, soy oil, which is the second most competitive oil, is not considered as flexible because it is determined by the demand for protein (Weidema 2003). Therefore, the identification of palm oil as the new marginal vegetable oil since 1999/00 appears quite solid.

3.2 Product system of palm oil applying system expansion in order to avoid co-product allocation

In the palm oil mill, the fresh fruit bunches (FFB) are threshed in order to separate the stalk tissue from the fruits. The fruits are pressed in order to extract palm oil and the kernels are sorted out from the press cake and sent to extraction in a palm kernel oil mill. Thus, palm kernel oil (PKO) is a co-product of palm oil production. This co-product can be dealt with in three ways: 1) Since PKO can be used for the same purposes as palm oil (see Table 1), it can be considered as a fixed proportion of any palm oil supply; 2) PKO can be considered as a dependant co-product which is dealt with by system expansion; or 3) PKO can be considered as a co-product which is dealt with by co-product allocation. As co-product allocation is avoided in consequential LCA, the last option is not considered here. Since there is some substitutability between PKO and the other oils in Table 1, we argue that palm oil and PKO together can be considered as one marginal oil supply. In the following, palm oil and palm kernel oil together are referred to as PO. Both the first and the second mentioned option lead to this recommendation. If palm kernel oil is considered as a dependant co-product, its marginal substitute is to be identified. The principal substitute for PKO is coconut oil (CNO). These oils are both lauric oils, which have a smaller application area than the seed oils, and the palm oil, as shown in Table 1. However, according to Weidema and Wesnæs (2006), CNO is considered constrained because it is a small-holders crop and because it takes 5–7 years to mature, which limits its ability to react easily on changes in market demand. Since there is some substitutability between PKO and other oils, we argue that the marginal substitute to PKO is to be found within the broad applications such as margarine and spreads where palm oil is considered as the marginal source.

In the product system of the marginal vegetable oil, the palm kernel meal created by crushing palm kernels should also be taken into account. The output of palm kernels per kg palm oil in Malaysia in 2004 was 0.262 kg (MPOB 2005, p. 15, 17). The output from processing 1 kg palm kernels is 0.450 kg palm kernel oil and 0.520 kg palm kernel meal (Oil World 2005). Thus, for each kg palm oil, there is an output of 0.118 kg palm kernel oil and 0.136 kg palm kernel meal. The palm kernel meal displaces marginal fodder

protein and fodder energy, which are identified as soy meal and barley, respectively (Weidema 2003). Since both soy meal and barley contain both protein and energy, the displacement of these crops should be balanced in order to maintain a constant supply of protein and energy, when performing system expansion on the palm oil system. When soy meal is displaced, it should be taken into account that one kg soy meal is co-produced with 0.233 kg soy oil (Oil World 2005). This decrease in soy oil supply will again affect the marginal oil, i.e. PO (palm oil and PKO). No significant co-products are related to the production of barley for fodder purposes.

The marginal producers of palm oil, soy bean and barley are assumed to be Malaysia and Indonesia for palm oil, Brazil for soy bean and Canada for barley. This is based on predictions in FAPRI (2006), where these regions are forecasted to face the largest gross increase in cultivation from 2005/06 to 2015/16. The yields in the above-mentioned regions are regarded as averages of 2004 and 2005: 19.37 ton FFB/ha for palm oil in Malaysia and Indonesia, 2.31 ton/ha for soy bean in Brazil and 3.19 ton/ha for barley in Canada (FAOSTAT 2006).

The product flows described above for palm oil, soy meal and barley are summarized in Fig. 3. The input of FFB to the palm oil mill in Fig. 3 is based on an oil extraction rate of 0.2003 kg crude palm oil per kg FFB in Malaysia in 2004 (MPOB 2005).

The protein and energy content of soy meal, barley and palm kernel meal are given in Møller et al. (2000). The energy content of animal fodder is denoted in Scandinavian feed units (FU). Using these data and the proportions between co-products given in Fig. 3, the production of palm oil and palm kernel oil (PO), soy meal (SM) and barley (BL) required to meet an increased demand of 1 kg vegetable oil is calculated by solving the equation system (1) shown below.

It appears from Eq. (1) that a change in demand for 1 kg vegetable oil requires 1.007 kg palm oil and displaces 0.028 kg soy meal and 0.066 kg barley. The reason why more oil than the demanded 1 kg is required is that the displaced soy meal is co-produced with soy oil. This 'missing' oil has to be compensated for.

Relating to primary crops and their corresponding land occupation in Fig. 3, Table 2 summarises the required amounts per demanded kg vegetable oil.

$$\text{kg PO} \cdot \begin{bmatrix} 1 \text{ kg oil/kg PO} \\ 18.1 \text{ g prot./kg PO} \\ 0.096 \text{ FU/kg PO} \end{bmatrix} + \text{kg SM} \cdot \begin{bmatrix} 0.233 \text{ kg oil/kg SM} \\ 430 \text{ g prot./kg SM} \\ 1.20 \text{ FU/kg SM} \end{bmatrix} + \text{kg BL} \cdot \begin{bmatrix} 0 \text{ kg oil/kg BL} \\ 92 \text{ g prot./kg BL} \\ 0.95 \text{ FU/kg BL} \end{bmatrix} = \begin{bmatrix} 1 \text{ kg oil} \\ 0 \text{ g prot.} \\ 0 \text{ FU} \end{bmatrix}$$

↓

$$\begin{aligned} \text{kg PO} &= 1.007 \\ \text{kg SM} &= -0.028 \\ \text{kg BL} &= -0.066 \end{aligned}$$

(1)

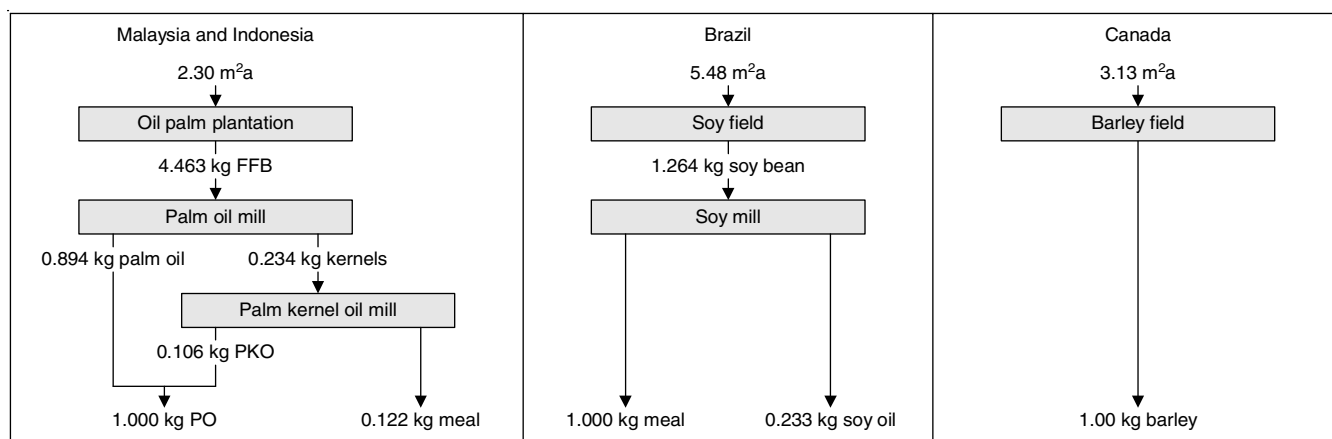


Fig. 3: Product flow in the product systems of palm oil (PO), soy meal and barley

Table 2: Required primary crops and corresponding land use related to 1 kg marginal oil

| Required crops and land per 1 kg demanded vegetable oil | Affected product system | | |
|---|-------------------------|------------------------|------------------------|
| | Oil palm | Soy | Barley |
| Primary crop | 4.49 kg FFB | −0.035 kg soy bean | −0.066 kg barley |
| Land occupation | 2.32 m ² y | −0.15 m ² y | −0.21 m ² y |

4 Conclusions and Discussion

This article provides a specific example of how to identify marginal technologies and how to deal with system expansion. There is great substitutability among different oils and many alternative oils can meet the same need. Therefore, the marginal vegetable oil or a range of affected oils should be included in future LCAs of vegetable oils. Based on a description of the market segment, vegetable oils that are able to react to changes in demand and price relation between oils, the marginal vegetable oil is identified as palm oil. A shift from rapeseed oil to palm oil has been identified around the year 2000. Secondly, it is shown that co-product allocation between oils and meal can be avoided by system expansion, by considering the energy and protein content in the meal, which displaces a mix of the marginal sources of energy and protein for animal fodder (barley and soy meal, respectively). Hence, it is shown that a change in demand for 1 kg vegetable oil requires 1.007 kg palm oil and displaces 0.028 kg soy meal and 0.066 kg barley.

The implications of a shift of the marginal vegetable oil from rape to palm are quite significant. Many LCAs of rape-based biodiesel, food products and other technical applications have been conducted and are currently used as decision support (Mehlin et al. 2003, De Nocker et al. 1998, SenterNovem 2005, Wightman et al. 1999, McManus et al. 2004, Nielsen et al. 2005 and Beer et al. 2002). If the methodological preconditions in the consequential models are accepted and the shift of the marginal vegetable oil is taken into account, many of the current LCAs of especially rapeseed and soy oil do not focus on what is actually affected by the decisions they were intended to support.

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